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MEASUREMENT AND ANALYSIS OF EVAPORATION FROM AN INACTIVE OUTDOOR SWIMMING POOL

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Abstract—Evaporation rates and total energy loads from an unoccupied, heated, outdoor pool in Fort Collins, Colorado were investigated. Pool and air temperatures, humidity, thermal radiation, wind speed, and water loss due to evaporation were measured over 21 test periods ranging from 1.1 to 16.2 hours during August and September, 1992. Data were analyzed and compared to commonly used evaporation rate equations, most notably that used in the ASHRAE Applications Handbook. Measured evaporation was 72% of the ASHRAE calculated value with near-zero wind velocity, and 82% of the ASHRAE value at 2.2 m/s wind velocity. A modified version of the ASHRAE equation was developed. Two overnight tests showed energy loss of 56% by evaporation, 26% by radiation, and 18% by convection. A correlation between radiation loss and temperatures was also found for the range of test conditions.

1. INTRODUCTION

There are over 5.9 million heated swimming pools and spas in the U.S. (National Spa and Pool Institute, 1987 & 1988), consuming billions of dollars of energy annually. Because of this significant energy use, the U.S. Department of Energy (DOE) has launched a nationwide campaign to reduce swimming pool energy costs, called *Energy Smart Pools*. Market-ready energy efficiency and renewable energy products such as pool covers, solar hot water systems, and windbreaks will be supported through information and technology transfer to pool owners.

Pool owners must have reliable information about the cost effectiveness of potential energy efficiency investments. Accurate engineering methods to calculate pool energy loads before and after measure implementation are required. Evaporation is the chief component of energy loss in pools, therefore, its prediction is very important. Energy analysts rely on methods presented in the technical literature, such as the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) handbooks. However, there is significant disagreement in the results of various evaporation rate equations when applied to swimming pools.

Evaporation rate calculation disparities are primarily due to a lack of good experimental data based on direct water loss measurement in pools. For this reason, DOE has sponsored a series of tests to measure evaporation and total energy loads in swimming pools. Tests have been conducted by the Solar Energy Applications Laboratory at Colorado State University. The background, procedures, and results of tests on an unoccupied, outdoor pool follow.

2. BACKGROUND

Measurements of water evaporation from pans and small tanks in wind tunnels have been made by previous investigators (Carrier, 1918; Rohwer, 1931). Evaporation from lakes and reservoirs have also been measured (Rohwer, 1931; Meyer, 1942). These results offer some information applicable to pools. However, water body geometries and surroundings differed from those of swimming pools, and they were also unheated.

The widely used ASHRAE Handbooks (1991) have for many years contained an evaporation rate equation based on experiments, primarily those of Carrier (1918);

$$W = \frac{(95 + 37.4V)(P_w - P_a)}{Y} \qquad (1)$$

W—evaporation rate, lb/hr-ft^2
V—air velocity over water surface, MPH
P_w—saturation vapor pressure at the water temperature, in. Hg
P_a—saturation vapor pressure at the air dew point, in. Hg
Y—Latent heat of water at pool temperature, Btu/lb.

The corresponding equation in SI units is:

$$\frac{\dot{m}}{A} = \frac{(42.6 + 37.6V_w)(P_w - P_a)}{\Delta H_v} \qquad (2)$$

where,
$\dot{m}/A$ is the evaporation rate, kg m^2 hr
V_w is the air velocity over water surface, m/s
P_w is the saturation vapor pressure at the water temperature, mm Hg
P_a is the saturation vapor pressure at the air dew point, mm Hg
ΔH_v is the latent heat of water at the pool temperature, kJ kg

In the 1991 Applications Handbook, there is a notation that the equation may be used for estimating evaporation from pools in active use, but under other conditions evaporation may decrease as much as 50%.

The accuracy of the ASHRAE evaporation equation for undisturbed and actively used pools has been questioned recently on the basis of German investigations (Biasin, Von, & Krumme, 1974; Reeker, 1978; Labohm, 1971). These reports show condensate collection from air dehumidifiers as functions of vapor pressure difference between the pool water and the air over a pool (the same form as the ASHRAE equation). They indicate condensate recovery rates from a quiet pool are substantially lower than evaporation determined by use of the above equation. However, condensate collection from dehumidifiers can be considerably less than evaporation because of ventilation losses and condensation on surfaces of the building.

Evaporation tests were conducted at Colorado State University during April of 1992 on an inactive indoor pool (Smith, 1992). Evaporation rates at constant, controlled conditions, measured over periods extending to more than 50 hours were found to average 74% of the values determined by use of the ASHRAE equation.

Outdoor pool energy estimates from Florida are available (Root, 1983) which are based on few measured results. Outdoor pools are subject to greater evaporation, radiation, and convection heat losses than occur in indoor pools. A major difference is due to wind or air movement as can be observed from the velocity component of the ASHRAE/Carrier equation.

Rohwer and others have developed wind velocity coefficients from laboratory measurements. Figure 1 illustrates wind effects upon evaporation taken from six references. Even considering the lowest wind coefficients (the lowest slopes of the lines), it is clear that evaporation is strongly influenced by air velocity.

3. OUTDOOR POOL EXPERIMENTS

In the CSU study, measurement of direct water loss, vapor pressure differences, and wind velocity in an outdoor swimming pool were used to provide a reliable method for predicting pool evaporation rates.

3.1. *Test site*

A neighborhood association pool with 383 square meters total surface area and 546 cubic meters volume was studied. Buildings, trees, and fences were set back 6 or more meters, and the pool was well exposed to wind and solar radiation. Outward radiation from the pool was almost entirely to the sky.

The pool water was circulated by conventional means through a sand filter, chlorinator, and gas-fired boiler. The pool was maintained at 28.9°C by a thermostat in the return water line from the pool. Natural gas billing records indicate energy input to the pool was approximately 8.4 GJ per day if not covered, and 5.8 GJ per day when covered for about 12 hours overnight.

3.2. *Methods and procedures*

Air and water conditions were monitored at 6-minute intervals by a data acquisition unit coupled to a desktop computer. The computer provided real time output of the evaporation rate by use of the ASHRAE equation and the corresponding drop in pool level.

Pool water temperature and air temperatures were measured with T-type thermocouple welded junctions. Thermocouples agreed to within 0.3°C with a precision scientific mercury-in-glass thermometer and within 0.1°C with each other. This precision includes the electronic signal conditioning and was repeatable during the testing period. Pool water temperature was measured at several locations during testing. There was no variation in water temperature.

Air humidity was determined by continuously monitoring the dew point temperature with an EG & G Model 660 dew point hygrometer. This instrument was calibrated just prior to testing to ±0.2°C against a secondary dew point temperature standard. The combined error of air temperature and dew point temperature measurement translates to approximately ±1.5% relative humidity.

Evaporation rates were determined by measuring the liquid volume loss during a time interval. The pool

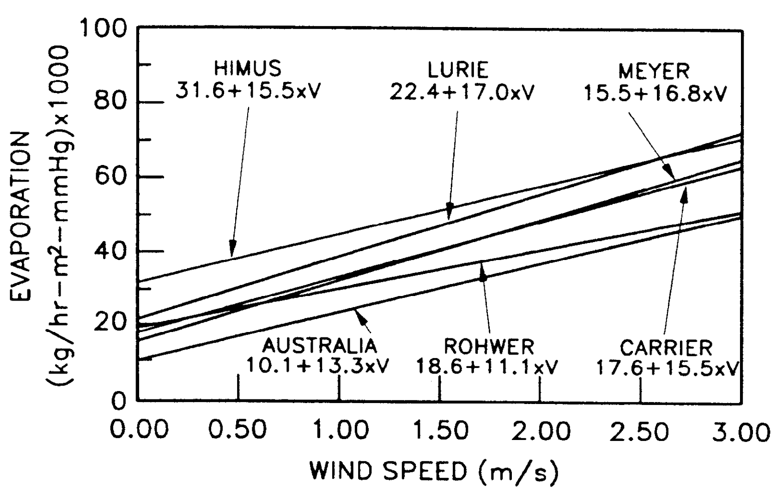

Fig. 1. Evaporation versus wind speed from non-pool references.

water level was measured by a microtector gauge rigidly mounted to the pool side. This gauge has a high precision adjustment and senses electrical contact with the water surface. The level measurements were observed inside a stilling well submerged below the surface, designed to suppress wave motion.

At typical conditions in outdoor pools, evaporation rates of about 0.5 Kg of water per hour, per square meter of water surface may be expected. At this rate, the water level in a pool will decrease about 0.5 mm/h. With suitable equipment, water levels can be measured to an accuracy of .025 mm, so the measurement of water level over a 4-hour period can yield an accuracy within about 2%. Water additions and discharges to the pool circuit were prevented during the test period.

Wind speed was obtained from a rotating cup anemometer located at the edge of the pool 0.3 meter above the water surface. Two radiation sensors; an Epley solar pyranometer, and a net radiometer were located on an extension arm over the pool. Radiation losses were computed as the difference between net radiation and the incoming solar radiation.

3.3. *Outdoor pool testing conditions*

There is no practical way of controlling the conditions over an outdoor pool such that a single parameter, such as the wind, could be investigated. Consequently, numerous observations were recorded for entry into a spreadsheet format so that the trends of interest would appear. There was a limit to the number of observations possible because evaporation water loss is slow relative to the measurement techniques available, and also because there were no more than 15 days available for testing. Most of the testing was conducted at night when the pool was inactive and the atmospheric conditions were steadier than in daytime. Night testing also improved the accuracy of total energy budget measurements by avoiding the influence of solar gain.

Testing periods of at least 3 hour duration were desired. However, winds were never steady for 3 hours and the resulting averages seldom exceeded 1 m/s. Because the wind term in previous evaporation equations was linear, it appeared that averages were sufficient for the purpose of obtaining a wind speed coefficient. Higher wind speed points would add confidence to the results, however. Thus a method of greater precision in water loss measurement was sought to reduce the time period requirements for testing.

3.4. *Evaporation pan measurements*

Floating evaporation pans were introduced midway into the testing program to permit short term evaporation measurement. Two shallow aluminum pans, 20 cm in diameter, were secured approximately 3 meters from the pool side by line and anchor. The evaporative water loss from the pans could be accurately determined at the pool site by periodic transfer of the water to a graduated cylinder. Typical water losses of 50 ml or more per hour could be measured to +/−1 ml; an accuracy of about 2%.

The thin aluminum material of the pans insured temperature equilibrium between the contents and the pool water. A least-squares straight line comparison of the pan measurements to the water level measurements showed a slope of 1.04, indicating pan evaporation rates approximately 4% higher than those in the pool. The cause of the small difference was not known, but it was consistent enough that pan evaporation could be used in short period tests by applying the 4% correction.

3.5. *Evaporation results*

The twenty-one evaporation tests ranged in length from 1.1 to 16.2 hours; the results are presented as hourly values for consistency. Evaporation water loss during short time periods under high wind conditions were obtained from two pan measurements. Wind velocities for the outdoor tests ranged between 0.1 and 3.2 m/s. Because there was no practical means to control either the wind or water vapor pressure difference, the test points are multivariant with respect to these parameters. To present evaporation as a function of wind velocity, the form of the evaporation equation can be rearranged as follows:

$$\frac{\dot{m}\Delta H_v}{A(P_w - P_a)} = (C_1 + C_2 x V_w) \tag{3}$$

where C_1 and C_2 are constants.

Figure 2 presents a straight line fit to the test data for water evaporation rate per unit of water vapor pressure difference versus the wind speed. Figure 2 also presents a comparison of the test results with the two most applicable evaporation references: ASHRAE (1991)/Carrier (1918) and Rohwer (1931). The test results yield SI coefficients of C_1 equal to 8.51 and C_2 equal to 8.92; or in the ASHRAE form of the equation:

$$\frac{\dot{m}}{A} = \frac{(30.6 + 32.1 v_w)(P_w - P_a)}{\Delta H_v} \tag{4}$$

Also indicated in Figure 2 is the evaporation rate found in previous indoor pool tests (Smith, 1993); 0.0136 Kg./Hr-m^2-mm Hg at 0.03 m/s air speed. This rate is nearly identical to the .0134 Kg./Hr-m^2-mm Hg at 0.03 m/s obtained in the outdoor tests.

Figure 3 presents the effect of wind velocity upon evaporation rate as determined by the above equation for a set of lines of equal vapor pressure difference. This form of presentation is intended to show the importance of wind and water temperature in pool evaporation.

3.6 *Radiation measurement*

Long wave radiation emitted from the pool surface to the surroundings was monitored each 6 min by sub-

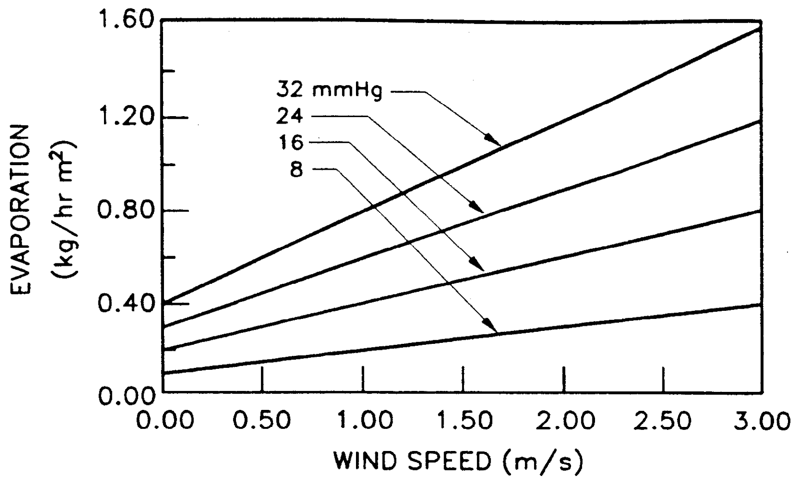

Fig. 2. Effect of wind speed on pool evaporation rate.

tracting the short wave solar radiation from the net radiation. Most of the testing was conducted with near zero solar radiation. The field of view from the pool water surface was almost entirely sky. Thus the equation for radiation heat loss from the pool surface is:

$$Q_r = \epsilon\sigma(T_{\text{pool}}^4 - T_{\text{sky}}^4), \tag{5}$$

where

$$T_{\text{sky}} = T_{\text{air}}\left[0.8 + \frac{(T_{\text{airdp}} - 273)}{250}\right]^{1/4} \tag{6}$$

The sky temperature (T_{sky}) ranges from about 10°C below ambient for hot humid conditions to 30°C below ambient in a dry cool climate (Bliss, 1961). For a specific climatic region, an approximate linear correlation is:

$$Q_r = C_3 + C_4 x(T_{\text{pool}} - T_{\text{air}}) \tag{7}$$

For the range of temperature difference experienced in these tests (approximately 5–17°C), the radiation heat loss fit the linear relationship:

$$Q_r = 25.1 + 34x(T_{\text{pool}} - T_{\text{air}}) \tag{8}$$

Data scatter suggests that this relationship is valid to within approximately 10%. The site conditions were relatively low humidity with clear skies, so radiation energy loss may be somewhat higher than the average in the United States.

3.7 *Total energy loss*

During two periods when no heat was supplied to the pool after it closed for the season on September 8, the total energy loss was measured. Under these conditions, the combined losses of evaporation, radiation, and convection were equal to the change in energy content of the pool water over the time period of observation. These measurements were made at night

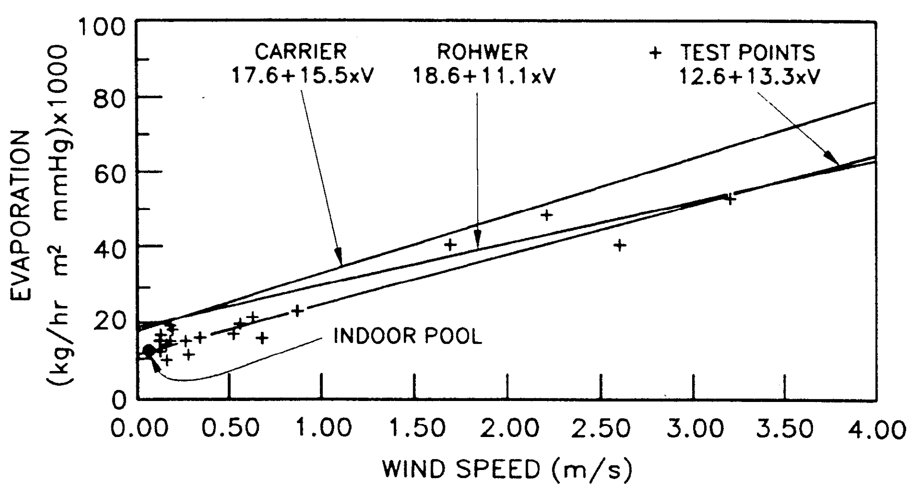

Fig. 3. Evaporation rate versus wind speed at selected vapor pressure differences.

with no incoming solar radiation. Evaporation and radiation were determined by the methods discussed above. Total energy loss was found from the change in pool temperature. Convection loss was obtained as the residual difference. Energy losses were 56% by evaporation, 26% by radiation, and 18% by convection.

4. CONCLUSIONS

The rate of evaporation from an inactive outdoor swimming pool is 16–28% lower than that predicted by the ASHRAE equation. In twenty-one closely monitored tests, at a pool temperature of 29°C, air temperature of 14.4 to 27.8°C, and relative humidity of 27–65%, the evaporation rate was 72% of the ASHRAE value at no wind velocity, and 84% of the ASHRAE value at 2.2 m/s wind speed. A linear fit to the test data yields an equation in the ASHRAE form but with adjusted coefficients:

$$\frac{\dot{m}}{A} = \frac{(30.6 + 32.1v_w)(P_w - P_a)}{\Delta H_v} \qquad (9)$$

This relationship also conforms closely to results found earlier for the inactive indoor pool (Smith, 1992).

Radiation loss was approximately one half the energy lost by evaporation. A correlation between radiation energy loss from the pool surface and temperature difference between the pool and air temperature was found for the range of conditions during testing. Heat loss by convection was approximately 18% of total losses.

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